Natural Disasters and the Yield Curve of Florida Valencias

by

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Abstract

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This study estimates a model of the age-yield relationship for Florida Valencia oranges as a Sigmoid curve using a modified hyperbolic tangent function. From this model, the absence of natural disaster risk in the lower interior region is shown to have resulted in a higher yield function compared to other areas of the state. It is also shown that the rate of technology adoption influences the yield function.

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I. Introduction

The Florida citrus industry has undergone a considerable transformation during the past fifteen years. As figure 1 shows, orange production has surged in the lower interior counties while tailing off dramatically in the upper interior region that had been historically a major orange producer.[1] A major reason for this shift south is thought to be the increased exposure to freeze damage in the upper interior counties. For example, the upper interior counties were hit particularly had when back to back freezes in 1983 and 1984 destroyed virtually all of the citrus groves. Additionally new technology has allowed production to occur in the lower interior regions where environmental conditions precluded production earlier. Critical to being able to examine the cause and effect of these production movements is an estimation of orange yield curves. In the past this has been hampered by the difficulty in identifying a supply function for Valencia oranges. This paper takes a first step towards identifying a reasonable supply function by estimating a model of the age-yield relationship for Valencia oranges. From this model, clear observable effects of reduced freeze exposure in the lower interior region are found. It is also shown that the rate of technology adoption influences the yield function.

Knowledge of certain physiological characteristics of orange tree growth is essential to understanding the model developed here. Orange trees demonstrate a high degree of juvenility, such that a young tree may require several years prior to bearing fruit.

[1] Upper interior counties include: Lake, Marion, Orange, Osceola, Putnam, Seminole, Sumter, and Volusia counties. Lower interior counties include: Charlotte, Collier, DeSoto, Glades, Hardee, Hendry, Highlands, Lee, Okechobee, and Polk counties.

To minimize such unproductive stages, growers graft a scion (the top part of the tree) onto a rootstock system. Choosing the rootstock and scion independently allows the grower to take advantage of specific horticultural characteristics of various cultivors. (Jackson et al., 1989) As a result, orange trees can become productive in as little as 3 years compared to the alternative 6-7 years. Also the surface area of the orange tree canopy is crucial to the yield of the tree. Unlike other crops like pecans, where fruit may develop anywhere in the canopy, oranges are found only on the outside surface area. Thus as a tree develops, it gains increased productive capacity. Overall the age of a particular tree plays a crucial role in determining how much fruit the tree will yield.

Several types of oranges are produced in Florida including: early, midseason and late (Valencia) varieties. Valencia oranges are the focus of this study, because the are the most suitable for juicing, and occupy the largest share of the Florida orange crop. Valencia oranges are particularly susceptible to freeze damage because they are not ready to harvest until the late winter months. Originally the major orange producing region of the state was the St. Johns River basin in the Northeast. After the freeze of 1894-95, production moved to an area known as the Ridge or the upper interior located roughly in the central part of Florida. After major freezes in 1957 and 1962, production edged south but was prevented from completely relocating in the South by the inclement growing conditions of the Florida wetlands. As new agronomic advances were made production became possible in the lower interior regions. After a series of record freezes during the 1980's in the upper interior counties, production made a final dramatic shift south. As a final illustration of the impact of this latest push south, figure 2 compares two representative counties, Lake county in the upper interior and Hendry county in the lower interior. After the back to back freezes of 1983 and 1984, orange production in Lake county virtually vanished, while production in Hendry county boomed. While overall production has changed only nominally the impact at the local levels has been substantial.

II. A Model of Regional Valencia Orange Yields

Given the importance of the age of an orange tree to its productive capacity, an understanding of the precise age-yield relationship becomes crucial to explaining shifts in orange production. Mathematically, the yield of an orange tree can be expressed as

$$Y = \sum_{i} \alpha_i \, \text{age}_i \qquad (1)$$

where α_i is the technical coefficient of production and is unique to each age cohort. A reasonable method of estimating α_i might be to employ a standard OLS regression. There are however several limitations to this approach. The most critical is the assumption implicitly made when using OLS that Y is a linear function of age. Such an assumption would mean that in each additional year a tree yields an equal increase in production. Evidence, however, suggests gains in yield level off at some maturity point and that in general the relationship between yield and time is nonlinear. Additionally, we have no *a priori* reason to believe that each year's change in yield is equivalent to the prior year's change.

Given such limitations it is not surprising that using OLS to model the age-yield curve produces undesirable results. In regressions not reported here, the OLS estimation produced several negative coefficients. These results clearly indict the appropriateness of the OLS model. The negative coefficients would suggest as the number of trees with the negative coefficient increases the lower the overall grove production declines. Such absurd results motivate the search for alternative functional forms.

Given the physiological characteristics of orange tree production a more reasonable hypothesis is that the functional form of the age-yield relationship follows a Sigmoid 'S' shape. That is, over the early years of a tree's life, the change in yield is relatively flat. As the tree grows older the change in yield increases more sharply until maturity where the growth rate flattens out once again. The hyperbolic tangent function produces such a functional form. A formal representation can then be expressed as:

$$\alpha_i = \frac{\beta_{\max}}{2}\{1 + \tanh(\beta_0 + \beta_1 age_i)\} \qquad (2)$$

where $\$_0$ is an intercept term, $\$_1$ is a slope parameter and $\$_{max}$ represents the maximum yield. Such a specification requires the curve to exist in a positive domain, with a symmetrical Sigmoid 'S' curve centered at $\$_{max}/2$. $\$_0$, as the y-intercept term, corresponds to the minimum level of production since the range of ages is strictly positive and thus the portion of the function to the left of the y-axis is meaningless. $\$_1$ allows for an unrestricted slope, thus allowing the function to take a variety of appearances including almost linear or a combination of convexities.

In order to estimate the model, we can substitute (2) into (1) to give an estimate of expected yield $\left(\hat{Y}\right)$. The $\$$ parameters are then estimated by nonlinear least squares. Formally, estimating the age-yield relationship can be expressed as the following minimization problem:

$$\underset{\beta_{\max},\ \beta_0,\ \beta_1}{\text{Min}} \ \sum_i (\hat{Y}_i - Y_i)^2$$

Given the sensitivity of nonlinear estimation to the initial values, the above minimization problem can be modified by substituting a linear approximation for the hyperbolic tangent function. The results of the linear function can be used as a "best guess" starting point for the original nonlinear model. After solving the nonlinear model for $\$\text{max}$, fixing $\$_0$ and $\$_1$, successive iterations can be performed alternating the parameters held fixed while substituting the previous results as the new "best guess" initial value. This iterative process is carried out until the marginal value of changing any parameter is close to zero.

III. Results

The above model was estimated for four separate citrus producing regions as defined by the Florida Department of Citrus. Panel data ranging from 1967-1993 across Florida counties provided the sample for estimation. Each observation consisted of the number of trees *i* years old, for *i*=3 to 24 for each county. This tree age profile was then matched to each county's level of production for the appropriate year.[2] Only trees at least 3 years old were included since younger trees are largely considered nonbearing. Age profile inventory data was constructed from various editions of the Florida Agricultural Statistics Service's (FASS) Tree Survey. Production data was taken from various issues of *Citrus Summary* also prepared by FASS.

Table 1 presents the estimated $\$$ parameters by region. Substituting those values into (2) the technical production coefficients can be calculated and are reported in table 2.

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[2] Some observations were excluded due to missing data. In particular, upper interior counties severely damaged by the 1985 freeze were excluded. Data was further limited since tree inventories were only conducted biennially.

Figure 3 graphically depicts the estimated yield-age functions. Quite clearly there are stark contrasts between regional yield functions. For all ages, citrus in the lower region yields considerably more fruit. Two factors together can explain this phenomenon. First production in most lower interior counties has only become possible recently because of new technology. The implication is that groves in the lower interior have been planted using the latest high yield horticultural innovations. Thus the contrasting yield functions in figure 3 might more appropriately be viewed as a contrast between old and new technologies rather than regional differences. However technology cannot be the sole factor at work. Assuming producers are rational, given such a clear advantage of new technology, all regions would adopt it. The result would be a single age-yield relationship instead of the four distinct curves found here.

Accounting for the regional differences in risk is the second factor at work. Natural disasters have to be considered. The lower interior region generally avoids freezes given its more tropical climate. In contrast, the upper interior region, as discussed earlier, has suffered extensive freeze damage at a variety of times. Even if a freeze does not destroy a tree, the damage to the fruit will result in lower production. Since the model of the yield function presented here is based on production data, lower production will translate into lower yields. If experimental data had been used the curve estimated would have described a simple biological yield function. Instead the model here implicitly incorporates intragegional economic relationship influenced by such factors as frost damage and differing rates of technology adoption.

Given the method of estimation, statistical testing of the results is nontrivial. Therefore only a qualitative evaluation of the model is offered presently.[3] Despite allowing the intercept term ($\$_0$) to vary without restriction, the estimate of $"_i$ for all regions closely matches the coefficient for 3 year old trees offered by Muraro et al. (1996a, 1996b, 1996c). For example, in the lower interior region Muraro reports an estimate of 0.7 while an estimate of 0.871 is reported here.[4] Additionally the age-yield curves are consistent with the *a priori* expectations of a smooth 'S' curve reinforced by the physiology of orange production. Finally, as noted above, the model produces results that are also consistent with known regional differences.

To further explore the economic implications of the specific yield functions, it is useful to consider the annualized gross margin of an acre of Valencia orange trees. This approach is superior to simply comparing yields since cost differentials across counties may more than offset higher yields. First we assume that all startup costs are contained in the first three years and that all revenue is generated in the third year and beyond. Further we assume a tree density of 120 trees per acre and that no tree loss occurs. The density assumption is reasonable in light of Muraro (1996) suggesting modern groves employ tree densities of up to 150 trees per acre. Given then the above assumptions an estimated yield can be calculated for the acre over each year of its life, for simplicity we assume the only relevant revenues are those occurring in the years 3-24. An estimated revenue can be

[3] Future extensions of this paper will employ the method of "bootstrapping" the standard errors to create a distribution that can then be used to perform hypothesis testing.

[4] For the upper interior Muraro 1996 reports .6 versus the result estimated here of .497. Similarly for the east Muraro 1996 finds a coefficient of 1 compared to .709 found using the model developed in section 2.

calculated by assuming a constant price of $5.32 per box that corresponds to the actual on-tree price of Valencia oranges in 1995-96.[5] Now the revenue calculated for the hypothetical acre for each age cohort can be viewed as a series of payments made annually over the course of 24 years, where the 1st three payments are zero. By discounting that stream of payments (assuming a 7% discount rate) and summing across years a total present value of the revenue produced per acre is calculated.

To facilitate comparison as well as allowing for the accounting of variable costs, the present value of revenue is more easily interpreted as an annualized value. The annualized revenue for each region is reported in Table 3. In order to account for differences in production costs among regions, the annual total per acre variable cost (also in table 3) is deducted from the annualized revenue.[6] The resulting values are the annualized gross margin or the profit to the owner not accounting for any startup costs. Obviously the lower interior is much more profitable than any of the other regions.[7]

IV. Implications and Conclusions

In light of the hypothesis regarding the cause of the yield differentials given above, these financial statistics hold important economic implications. For example, assume that all differences are caused by differential exposure to freeze damage. Under such a scenario, any new freeze protection technology must be implemented at a cost less than or

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[5] The on-tree price represents the price received by the grove owner for a box net the cost of picking and hauling.

[6] The annual costs used here are taken from Muraro 1996a, 1996b, and 1996c. They represent the average variable cost for the 5 year period preceding 1995.

[7] The strongly negative value for the east region may in part be explained by the fact that oranges grown in the east are generally sold in the fresh market. Thus results for the east region may not be comparable to the juice oranges of the other regions.

equal to the differential in annualized gross margin. Relative to the upper and lower interior this differential is $346.35 an acre per year. Further these results have the potential to explain the failure of grove owners to replant in the upper interior region following the devastating freezes of the early 80's. To this day a great deal of the former grove land sits idle. Given the low gross margin found for the region of only $155.20 an acre, it is more than reasonable that after accounting for start up costs the economic rents to owners are close to zero. Thus rational owners appear to be those who replanted further south thus reinforcing the shift in orange production.

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FIGURE 1: Valencia Orange Production

Regional Comparisons

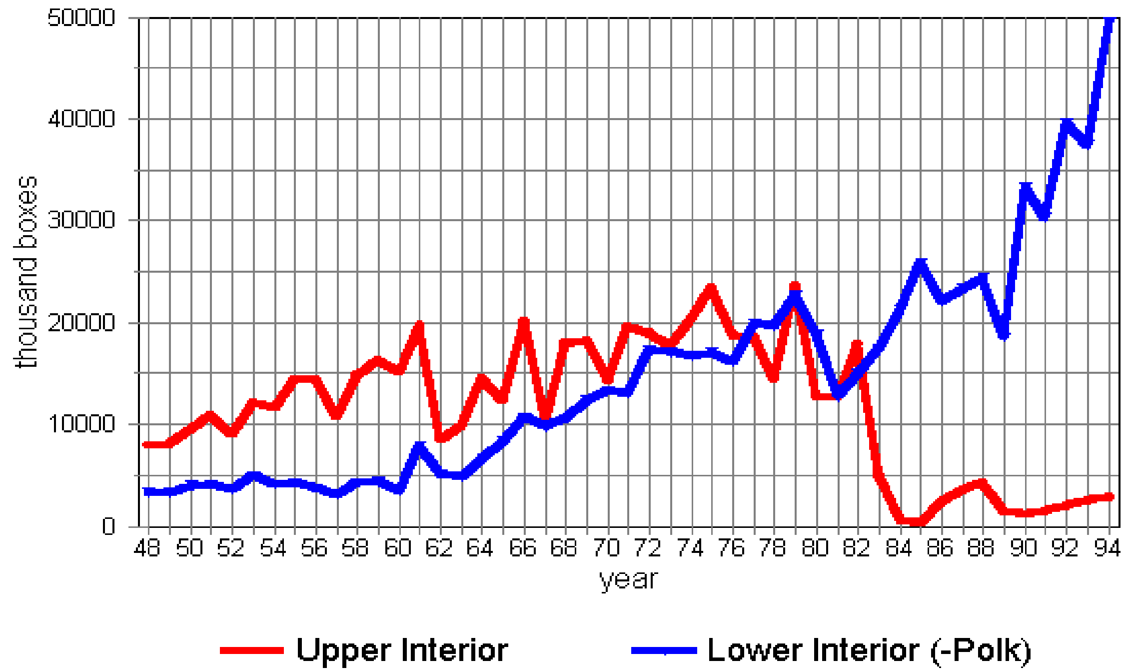

FIGURE 2: Valencia Orange Production

Selected County Comparison

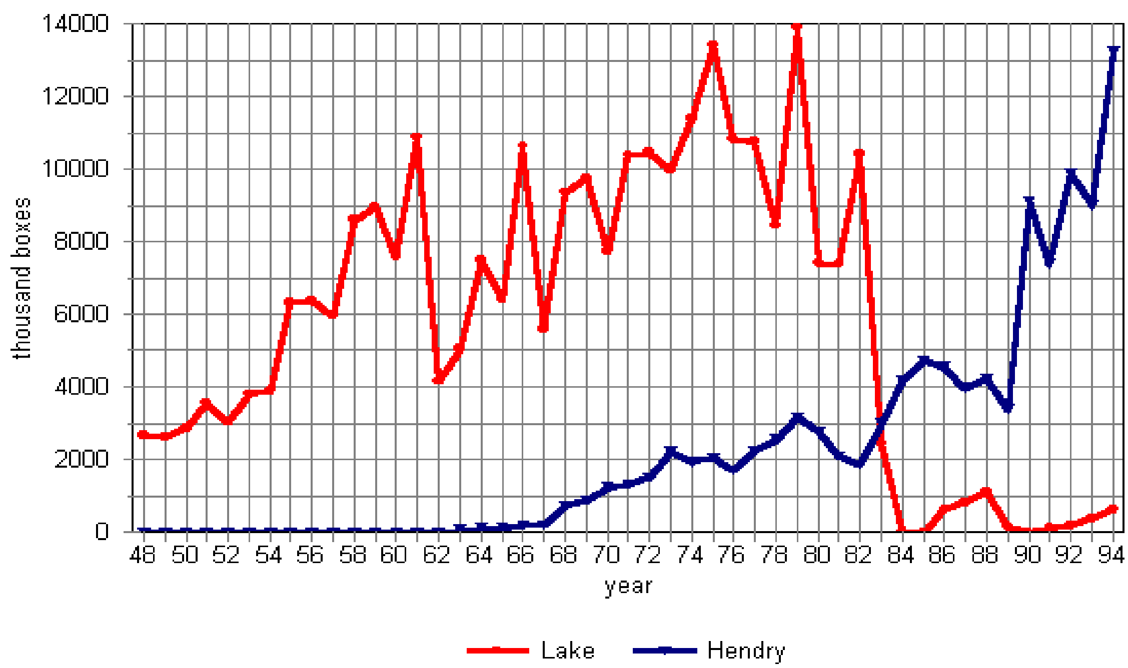

FIGURE 3: Productivity vs. Age of Tree

Florida Valencia Orange Trees

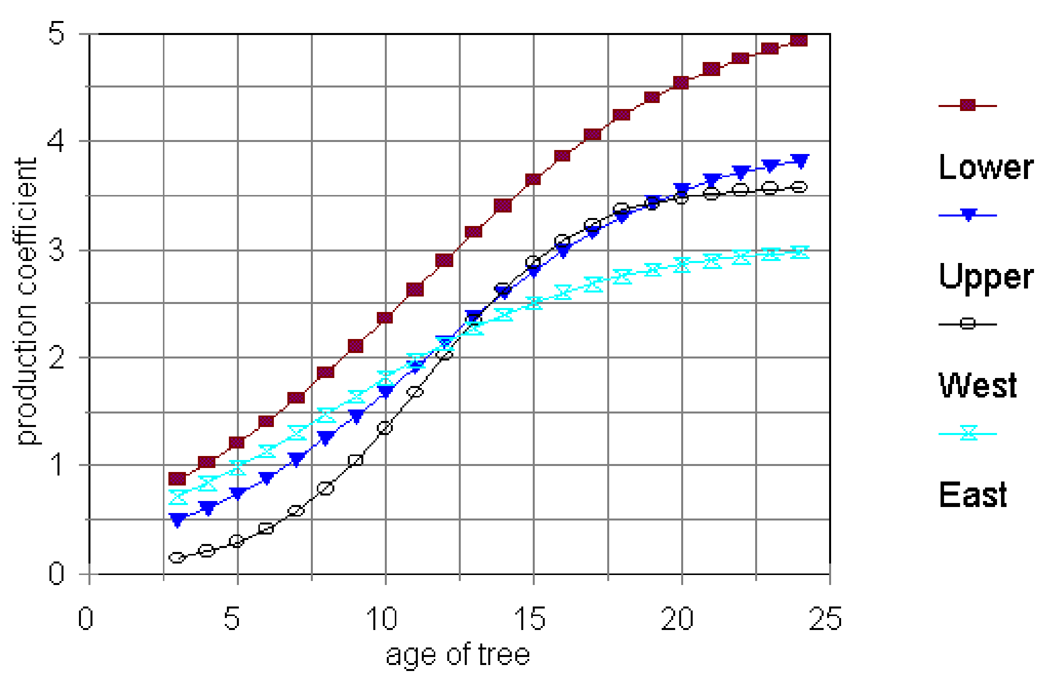

Table 1
$ Parameters by Region

Parameter	Lower	Upper	West	East
$\$_{max}$	5.294	4.033	3.606	3.073
$\$_0$	-1.115	-1.329	-2.161	-0.938
$\$_1$	0.101	0.116	0.19	0.112

Table 2
Technical Production Coefficients by Regions
Valencia Orange Trees

Age Of Tree	Lower	Upper	West	East
24	4.93	3.824	3.577	2.983
23	4.855	3.773	3.563	2.961
22	4.767	3.711	3.544	2.934
21	4.663	3.635	3.516	2.901
20	4.543	3.544	3.475	2.861
19	4.403	3.436	3.418	2.813
18	4.244	3.308	3.37	2.754
17	4.064	3.159	3.226	2.684
16	3.864	2.99	3.076	2.602
15	3.644	2.801	2.88	2.505
14	3.407	2.594	2.635	2.394
13	3.156	2.373	2.343	2.268
12	2.895	2.143	2.017	2.128
11	2.629	1.91	1.675	1.976
10	2.363	1.679	1.343	1.813
9	2.103	1.457	1.041	1.644
8	1.854	1.249	0.783	1.472
7	1.619	1.058	0.575	1.302
6	1.402	0.887	0.414	1.137
5	1.204	0.737	0.294	0.982
4	1.027	0.607	0.206	0.839
3	0.871	0.497	0.144	0.709

Table 3:
Financial Implications of Age-Yield Relationship
Annualized at 7% over 24 years

	Revenue	Cost	Gross Margin
Lower	$1,371.86	$870.23	$501.63
Upper	$1,002.17	$846.89	$155.28
West	$866.18	$870.23	($4.05)
East	$971.84	$1,085.39	($113.55)